TEST OF QCD PREDICTIONS FOR MULTIPARTICLE PRODUCTION AT LEP

O. PASSON
Fachbereich Physik, Bergische Universität-GH Wuppertal, Gaußstraße 20, D-42097 Wuppertal, Germany
E-mail: Oliver.Passon@CERN.CH

I discuss various QCD tests for multiparticle production, such as multiplicities, dead-cone effect and inclusive spectra. The common feature of all these predictions is the crucial importance of coherence effect to be taken into account.

1 Charged Particle Multiplicities

Among the most general features of e^+e^- annihilation one can look at is the charged particle multiplicity. Its mean value is predicted as a function of two free parameters: α_s and the constant a in the following formula:

$$\langle n_{ch}\rangle(Q) = a\alpha_s(Q)^b \exp c/\sqrt{\alpha_s}[1 + \mathcal{O}(\sqrt{\alpha_s})]$$

The constants b and c entering in this expression can be calculated, and especially in the result for c enters crucially the assumption of coherence: neglecting the effect of angular ordering would increase it by a factor of $\sqrt{2}$. The data up to the highest energies keep to be in fair agreement with this prediction [1] (see Fig.1). An important point in this measurement is that the LEP data have been corrected for the different b quark fractions.

The ratio of mean and dispersion is predicted to have a very mild energy dependence, or even to be energy independent according to the KNO scaling property. Also these predictions are met by the data within errors.[1]

2 Dead Cone Effect

It was mentioned above that the mean multiplicities were corrected for the different b quark fraction, since *this* QCD calculation treats quarks as massless particles. A prominent example for a mass effect as predicted by QCD is the so-called dead-cone-effect, which originates from the fact that radiation from a massive object is suppressed in a cone with half opening angle m/E. Evidently, this has the strongest effect on the ≈ 5 GeV heavy b quark, but happens to be still hard to detect directly. As a consequence of the suppressed radiation, the difference between the mean multiplicity of b and light quark events is predicted to be energy independent.[2] Fig.1 b) shows this multiplicity

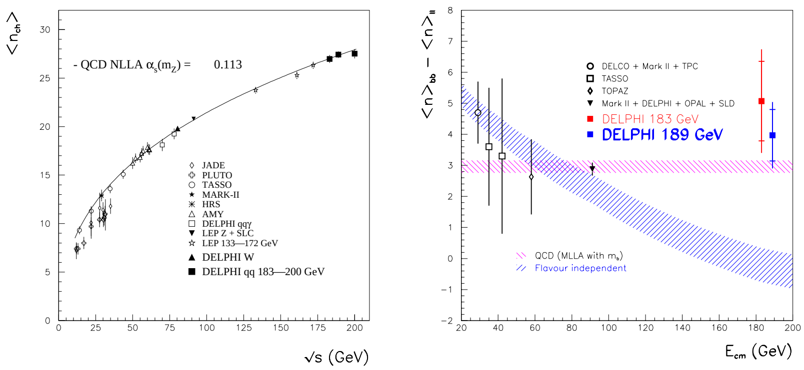

Figure 1. a) Charged multiplicities at various E_{CM} up to 200 GeV b) Energy dependence of the differnce between mean multiplicity for $\mathrm{b\bar{b}}$ and light quark events.

difference as a function of energy.[3] Indeed the LEP2 data confirm the coherent scenario, while in the naive approach one expects a decreasing influence of any mass effect in the limit of higher energies.

3 Inclusive Spectra

Let us now turn back to a more general feature, the inclusive spectra of all charged particles. The textbook example for the analytic perturbative approach is the ξ_p distribution, and the energy dependence of its maximum, ξ^*. In the limited spectrum approximation the distribution is predicted as a function of two free paramters: Λ_{eff} and the normalization K, which relates parton and hadron level. For the maximum ξ^* the K dependence drops out evidently. Fig.2 shows the distribution as measured by OPAL [4] at 189 GeV. The dashed line is a fit of the MLLA calculation to the data where the value of Λ_{eff} was fixed at 250 MeV and only the normalization K was fitted. As for the maximum ξ^*, only the incoherent COJET model is unable to describe the situation properly. It should be noted, however, that the assumed energy independence of the normalization K is only observed on a 10% level.[4]

Since the scaled momentum may vail the effect with an absolute scale, it is also of interest to look at the differential cross-section for the unscaled momentum $E\mathrm{d}n/\mathrm{d}^3p$. In the low momentum range, the calculation[5] of this quantity exhibits the interesting feature of universality: just from looking at the low energetic part, one cannot tell if the annihilation took place at 50 GeV,

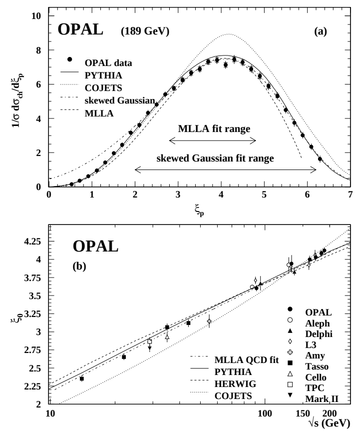

Figure 2. ξ_p distribution and energy dependence of its maximum, ξ^*.

200 GeV or even higher energy. This is understood as a consequence of the coherent emission of soft particles which cannot resolve the structure of the underlying event. The same feature shows up also in $p\bar{p}$ collisions. Fig.3 a) compares the DELPHI data from 91 to 200 GeVin $dn/d\ln p$ with the MLLA calculation, while Fig.3 b) shows the same quantity as measured by CDF[6] for different invariant masses of the two-jet systems ranging from 80 to 500 GeV. Both data sets show the predicted universality in the soft part due to

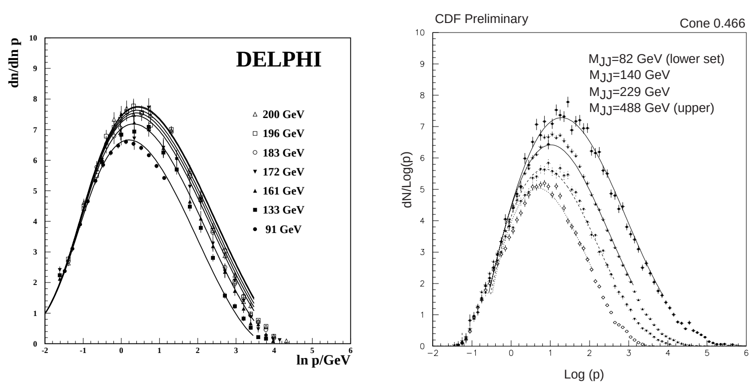

Figure 3. a) Differential cross–section in $\ln p$ for e^+e^- data from 91 to 200 GeV. b) The similar observable in $p\bar{p}$ collisions.

coherent emmission.

4 Cone Multiplicity Perpendicular to the 3-Jet Plane

Another test for coherent emission is provided by measuring the multiplicity perpendicular to the event plane in a three-jet event. This quantity has been calculated[5] as a function of the opening angles between the three jets. The physics behind this observable is the observation that, depending on the opening angle between gluon and quark jet, the extra colour charge of the gluon gets screened more or less. The DELPHI analysis [7] uses symmetric three-jet events, which makes it essentially unnecessary to identify the gluon jet. Additionally, the formula simplifies to the expression:

$$N_{\perp}^{\mathrm{q\bar{q}g}} \sim \left(2+\cos\frac{\theta_1}{2}-\cos\theta_1-\frac{1}{N_C^2}(1+\cos\frac{\theta_1}{2})\right) \ ,$$

where θ_1 is the angle between the two low-energetic jets. Fig. 4 a) shows the data compared to this prediction. Indeed the measurment is in excellent agreement with the prediction.

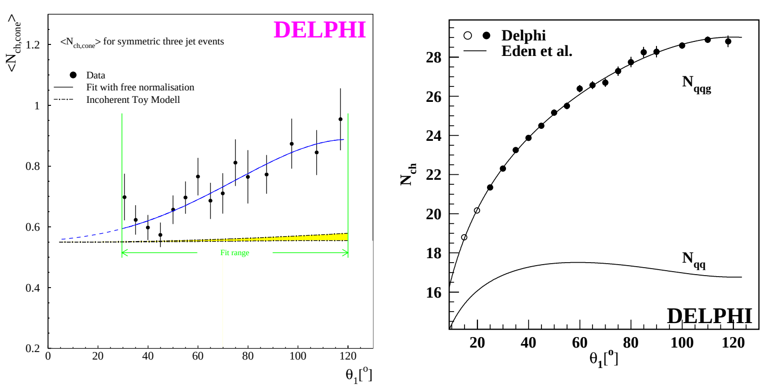

Figure 4. a) Cone multiplicity perpendicular to the event plane as a function of the opening angle between the two less energetic jets. b) Multiplicity in symmetric three jet events as a function of the angle between the two less energetic jets. The full line is a fit of the Eden et al. prediction as discussed in the text. The phase space restricted $\mathrm{q\bar{q}}$ contribution is displayed as the lower line.

5 Multiplicity in 3-Jet Events: $C_\mathrm{A}/C_\mathrm{F}$

Of course there are more obvious things one can do with three jet events, like accesing the colour factor ratio $C_\mathrm{A}/C_\mathrm{F}$, and thus the fundamental difference between gluons and quarks. The DELPHI analysis for this measurment uses as starting point the following equation,[8] which relates the scale dependence of gluon and quark multiplicities:

$$\frac{\mathrm{d}N_{\mathrm{gg}}(L')}{\mathrm{d}L'} \sim \frac{N_\mathrm{C}}{C_\mathrm{F}}\frac{\mathrm{d}N_{\mathrm{q\bar{q}}}}{\mathrm{d}L}$$

with $L = \ln s/\Lambda^2$ and $L' = L + 11/6 - 3/2$. Thus, by knowing the multiplicity in $\mathrm{q\bar{q}}$ events, the multiplicity in gluon–gluon events can be derived. In order to fix the boundary condition for this differential equation, CLEO data on Υ dacays can be used. This constant of integration takes essentially non–perturbative effects into account. Finally, the multiplicity in three jet events can be expressed as:

$$N_{\mathrm{q\bar{q}g}} = \frac{1}{2}N_{\mathrm{gg}}(\kappa_{\mathrm{Le}}) + N_{\mathrm{q\bar{q}}}(L_{\mathrm{q\bar{q}}}, \kappa_{\mathrm{Lu}})$$

with $L_{\mathrm{q\bar{q}}} = \ln s_{\mathrm{q\bar{q}}}/\Lambda^2$, $\kappa_{\mathrm{Lu}} = \ln s_{\mathrm{qg}}s_{\mathrm{\bar{q}g}}/s\Lambda^2$ and $\kappa_{\mathrm{Lu}} = \ln s_{\mathrm{qg}}s_{\mathrm{\bar{q}g}}/s_{\mathrm{q\bar{q}}}\Lambda^2$. The quark multiplicity entering in this expression is not exactly the directly measured one, but a "phase-space restricted" $\mathrm{q\bar{q}}$ multiplicity. This seemingly incoherent sum of the two contributions takes the coherence effect into account by a proper choice of the evolution scales κ.

For the test of this prediction DELPHI[9] uses again symmetic three-jet events, thus that the whole event is characterized by one angle only. The multiplicity of the *whole* events as a function of this angle is now predicted as a function of four quantities: The known $\mathrm{q\bar{q}}$ multiplicities, the constant of integration from solving the differential equation (fixed by CLEO data as mentioned above), a multiplicity off–set N_0 for taking b quark effects into account and the colour factor ratio $C_\mathrm{A}/C_\mathrm{F}$.

Note that only the *whole* event multiplicity is measured and any unphysical subdivision into "jet multiplicities" is avoided. Fig. 4 b) shows a fit of this prediction to the multiplicity in symmetric three-jet events. For the two fitted parameters this yields (with statistical errors) $C_\mathrm{A}/C_\mathrm{F} = 2.262 \pm 0.032$ and $N_0 = 0.760 \pm 0.047$.

By subtracting the quark contribution, one can get the multiplicity in gluon-gluon events, as shown in Fig. 5 a), upper line. Here, the angular dependence of the multiplicity is translated into the energy dependence according to the p_t like κ scale. The line which describes the gluon data is this time not a fit, but the absolut prediction of the calculation.[8] The gluon

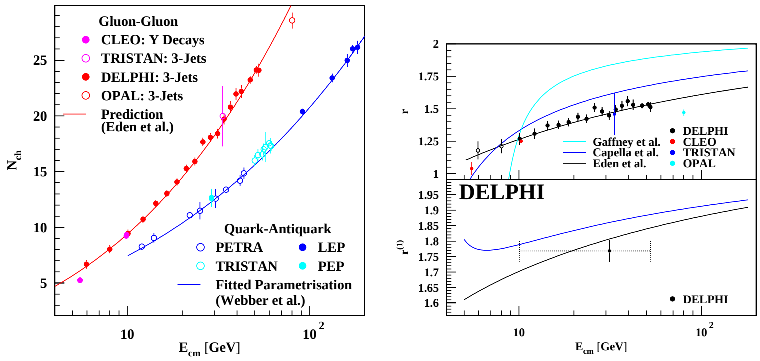

Figure 5. a) Multiplicity in gg events as extracted from the measurement compared to quark multiplicities. b) gluon and quark multiplicity ratio (top) and multiplicity-slope ratio (bottom).

multiplicities displayed in Fig.5 are not only LEP1 results but also CLEO and TRISTAN measurements at 10 and 58 GeV, respectively. Fig.5 b) shows r, the ratio of gluon and quark multiplicities. Its deviation from 1 was the first clear evidence for the bigger colour charge of gluons, although it evidently does not provide a direct measure of $C_{\rm A}/C_{\rm F}$. It has also been calculated by other groups, as indicated in the plot, but due to neglected non–perturbative effects these predictions do not describe the data. The lower plot in Fig.5 b) shows the slope–ratio $r^{(1)}$ of the multiplicities. Here, the deviation between the different calculations is less severe, since the multiplicity slope is less affected by non–perturbative effects.

References

1. DELPHI Coll. CERN-EP/2000-23.
2. B.A. Schumm *et al*, *Phys. Rev. Lett.* **69**, 3025 (1992).
3. DELPHI Coll. CERN-EP/2000-10.
4. OPAL Coll. CERN-EP/99-178.
5. V.A. Khoze *et al*, *Phys. Lett.* B **394**, 179 (1997).
6. A. Safonov, *Nucl. Phys.* B **86** (Proc.Suppl.), 55 (2000).
7. DELPHI Coll. DELPHI, 99-115 CONF 302.
8. P. Eden, G. Gustafson and V. Khoze, Eur.Phys.J.C11 345-350 (1999)
9. DELPHI Coll. CERN 2000-134.